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Axle load trends in Hungary and their effects on pavement structural design

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Abstract

A network of weight-in-motion sites has been implemented in Hungary in 1996. Measured data series provide a possibility for analyzing axle load trends in recent years. Both axle loads and total weights show an increasing tendency. Proportions of heavy vehicle categories have changed, too. According to the trends new design load classes were incorporated into the design guide a few years ago. A pavement strengthening program has been started on TEN-T and E-roads in order to comply with the EU 11,5 ton axle weight limit. Realistic axle load spectra and trends have been considered in the structural design of pavements.

Keywords: axle load; heavy vehicle; pavement strengthening; pavement design; weigh-in-motion

1. Introduction

Heavy vehicle traffic on roads has grown significantly in the past decades within the European Union, especially on transit routes. Despite continuous effort aiming the environmentally desired change in modal split, road transport still remained the main mode using heavy trucks and semi-trailers.

Load bearing capacity of pavements in recently joined EU Member States seems to be inadequate. This fact is underlined by some derogation got by new member states concerning maximum permitted axle loads. Pavement strengthening programs have been started in most countries co-financed by EU funds.

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2. WIM measurements in Hungary

A network of about 30 weight-in-motion (WIM) sites has been implemented in Hungary in 1996 co-financed by a World Bank loan. Since then dynamic axle load measurements have been performed regularly until 2010. Every year a calibration of the WIM sites took place to ensure reliable data. Measured data series provide a possibility for analyzing axle load trends in the past 10 years.

Processing of the huge amount of WIM data (millions of heavy vehicle axles) started with outlier analysis applying ISO 5725-2 Grubbs' outlier test. The remained good quality data have been organized into a database for further analysis, containing axle load measurement results sorted out by

- year (2000-2009),
- site (at least 10 different sites per year),
- vehicle axle pattern class (2 for buses, 2 for heavy trucks, 2 for truck+trailers, 4 for semi-trailers),
- axle position (from 1^{st} to 6^{th}).

The Hungarian WIM database has already been used for working out an enhanced Pavement Design Guide and establishing a development program for overload control and enforcement.

3. Growth of heavy traffic in recent years

National traffic census data time series indicate an almost permanent growth of heavy vehicles. The structure of heavy vehicle categories have changed in recent years. The proportion of truck and trailers has remained steady while the proportion of semi-trailers has increased significantly.

The traffic performance of heavy vehicles (vehicle kilometers travelled) has increased similarly as illustrated on Figure 1. The growing proportion of semi-trailers in the total VKT is clearly visible.

Accession years of new member states resulted in a higher step of heavy vehicle traffic growth. This was the case in 2004 when Hungary, Slovakia and some other countries have joined the EU. Heavy vehicle transit traffic has jumped high in 2007, the year of accession of Romania and Bulgaria since these countries are connected to the western part of Europe through Hungary.

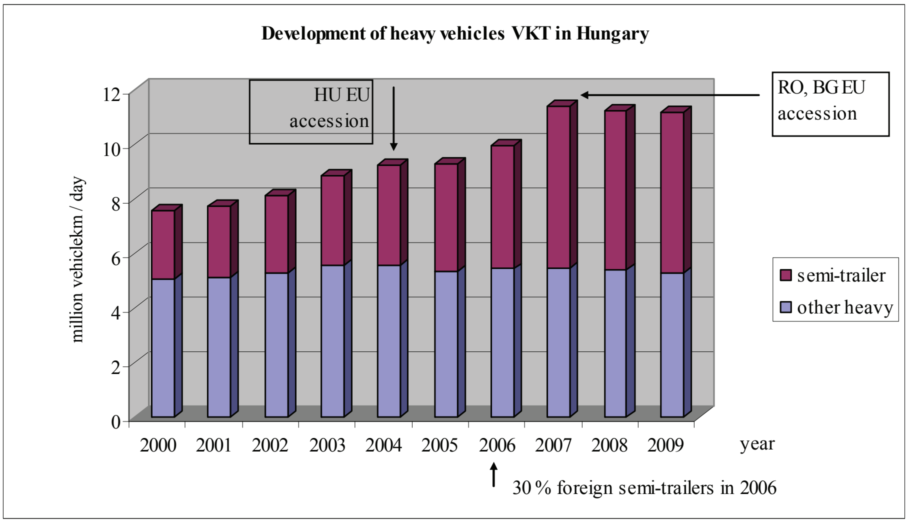

Fig. 1. Development of heavy vehicle VKT in Hungary

4. Axle load trends in the past decade

Axle load changes in time have been analyzed taking into account 2 periods:

- before and at the EU accession of Hungary, data from years 2002-2004,
- after the EU accession of Romania and Bulgaria, data from years 2008-2009.

Average values of measured axle loads by vehicle axle pattern class and axle position are shown in Tables 1 and 2, for years 2002-2004 and for years 2008-2009, resp. These tables provide information on total measured axles and summarized axle loads for each vehicle class, the latter being a good estimation of gross weight. Since WIM measurement is dynamic, gross weight of vehicles can be only estimated.

Both axle loads and total weights of heavy vehicles show an increasing tendency in accordance with the growth factors of heavy traffic. Data from years 2008-2009 are higher in almost all vehicle classes and axle positions compared to data from years 2002-2004, consequently total load of most vehicle classes are higher as well. The average value of total load of heaviest truck+trailers in years 2008-2009 even exceeded the legal limit (40 tons) that means a considerable number of overweight vehicles.

The most frequent vehicle class is the 1+1+3 semi-trailer. Figure 2 illustrates change of axle loads of this vehicle class in time showing a definite growth in case of all axles and axle group.

Remark: 1 ton = 1000 kg, corresponding force is 9,81 kN, for an 11,5 ton axle 112,8 kN (COST 323).

Table 1. Average values of measured axle loads in 2002-2004 [tons]

vehicle class	axle pattern	measured	1st axle	2nd axle	3rd axle	4th axle	5th axle	6th axle	total load
bus	o--o	329 841	5,19	9,62					14,81
articul. bus	o--oo	76 373	6,02	7,53	6,28				19,83
truck	o--o	682 143	3,60	5,85					9,45
truck	o--oo	183 587	5,51	6,96	5,73				18,20
truck+trailer	o--o-o-o, o--o-o-oo	427 125	5,05	6,90	4,46	4,48	4,98		25,87
truck+trailer	o--oo-o-o, o--oo-o-oo	166 899	6,35	8,43	5,74	6,44	6,16	5,43	38,55
semitrailer	o-o---o, o-o---oo	285 701	5,07	5,33	4,13	3,71			18,24
semitrailer	o-o---ooo	1 500 181	6,11	7,82	5,76	5,37	5,40		30,46
semitrailer	o-oo---o, o-oo---oo	49 675	6,08	8,15	7,02	6,90	7,16		35,31
semitrailer	o-oo---ooo	13 405	5,55	6,03	5,82	5,57	5,67	5,73	34,37

Table 2. Average values of measured axle loads in 2008-2009 [tons]

vehicle class	axle pattern	measured	1st axle	2nd axle	3rd axle	4th axle	5th axle	6th axle	total load
bus	o--o	676 585	5,75	9,62					15,37
articul. bus	o--oo	1 608	5,35	6,82	5,94				18,11
truck	o--o	193 586	2,47	3,42					5,89
truck	o--oo	13 963	6,11	7,62	5,79				19,51
truck+trailer	o--o-o-o, o--o-o-oo	838 799	5,31	6,65	4,34	4,30	5,20		25,79
truck+trailer	o--oo-o-o, o--oo-o-oo	265 795	7,25	8,67	5,82	7,08	6,71	5,31	40,83
semitrailer	o-o---o, o-o---oo	1 430 213	6,05	6,36	4,07	4,04			20,51
semitrailer	o-o---ooo	6 437 635	6,75	8,41	5,70	5,70	5,65		32,21
semitrailer	o-oo---o, o-oo---oo	201 911	6,64	8,02	6,83	6,72	6,11		34,31
semitrailer	o-oo---ooo	32 875	6,27	5,75	6,47	5,66	5,65	5,63	35,41

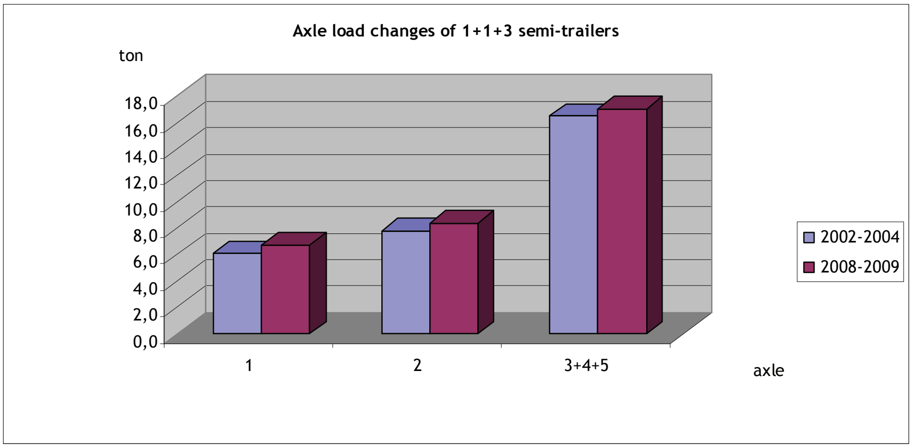

Fig. 2. Change of axle loads of 1+1+3 semi-trailers in time

Axle loads play an important role in pavement structural design both in case of new pavements and in case of strengthening existing pavements. Axle loads are taken into account by their damaging effect.

Calculation of damaging effect in case of flexible (asphalt) pavements is based on the so called fifth power law that means damaging effect of loads on the pavement is proportional of the fifth power of loads applied. Former research like the AASHO test (Transportation Research Board) reported the power of 4 but recent research on flexible pavements with a semi-rigid base course indicated that the power of 5 describes better the behavior and deterioration of these pavements.

Change in damaging effect as an example has been calculated for semi-trailers with axle pattern 1+1+3 applying equation 1:

$$d = \sum_{i=1}^{t} \frac{T_{i2}^{h}}{T_{i1}^{h}} \tag{1}$$

where T_{i2} and T_{i1} are axle loads in different times and h is the power of the damaging factor (h=5)

According to calculations based on measured data the summarized damaging effect of axles of the most frequent semi-trailer in Hungary (axle pattern 1+1+3) has increased significantly, by 39% in recent years (see Table 3.).

The change of damaging effect is even higher concerning the 1st steering axle (65%) and the 2nd driven axle (44%) of the analyzed vehicle class, the 1+1+3 semi-trailer. There is a 6,5 ton UN proposed load limit for steering axles that is exceeded by recently measured vehicles.

Table 3. Increase of the damaging effect of axles of 1+1+3 semi-trailers in time [tons]

axle	1	2	3	4	5	total
2002-2004	6,11	7,82	5,76	5,37	5,40	30,46
2008-2009	6,75	8,41	5,70	5,70	5,65	32,21
damaging proportion	1,646	1,439	0,949	1,347	1,254	1,390

5. Changes of loads of the second axle of the 1+1+3 semi-trailer on transit and non-transit routes

Axle loads are the highest on the second (driven) axle of the 1+1+3 semi-trailer therefore a detailed time-series analysis has been made distinguishing between transit and non-transit routes. The aim of this analysis has been to recognize any differences of axle loads on one hand in time and between transit and non-transit routes on the other.

WIM sites have been grouped into sites on transit routes and sites on non-transit routes. Each year weighed average values of measured data in both groups have been calculated for all load bins and relative load frequency distributions have been compared (Austroads). Figures 3 and 4 show the summarized results based on a large number (Table 4) of measured axle load data.

Remark: year 2004 in Figures 3 and 4 and Table 4 in this paper covers years 2002-2004 processed as a unified data set.

In both cases (transit and non-transit routes) axle loads show a definite increase in time. However this increase is more characteristic in case of transit routes where clear clusters can be identified for 2000-2004 and for 2007-2009.

Comparing axle loads on transit and non-transit routes some other important findings are as follows:

- Proportion of empty runs (the first peak on the curve) on non-transit routes is higher reflecting some lack of effectiveness in organization of domestic transport.
- Proportion of overloaded axles is higher on non-transit routes (about 7%) than on transit routes (about 4%) since in transit transportation there are weight control stations at border crossing points. This fact implies a demand for better enforcement in case of domestic heavy vehicles.
- On transit routes more vehicles are loaded up to legal limits (96/53 EC regulation, concerning axle loads and gross weight as well) than on non-transit routes. This fact shows that transit transportation has a higher effectiveness.

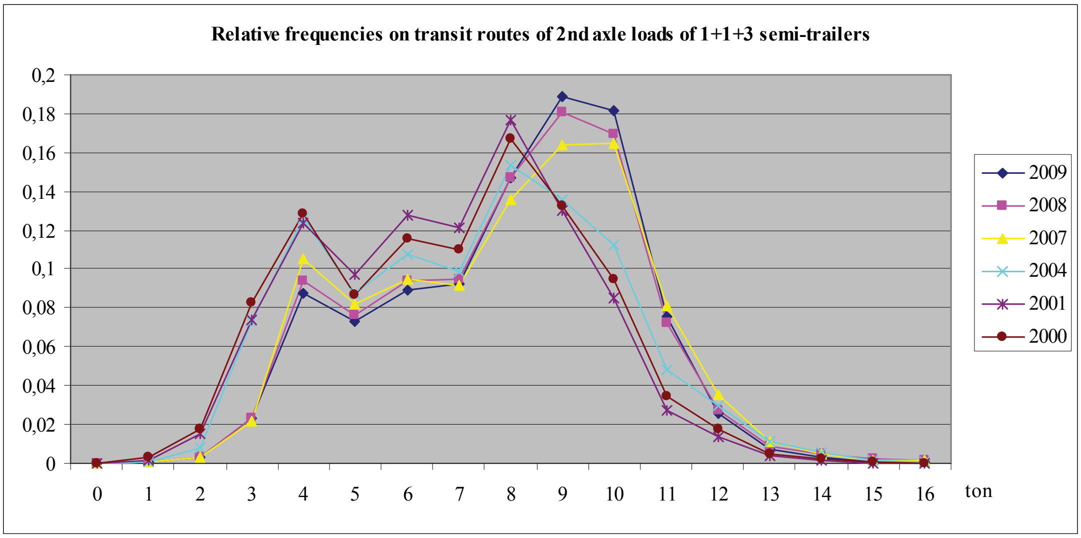

Fig. 3. Relative load frequency distribution on transit routes of 2nd axle loads of 1+1+3 semi-trailers

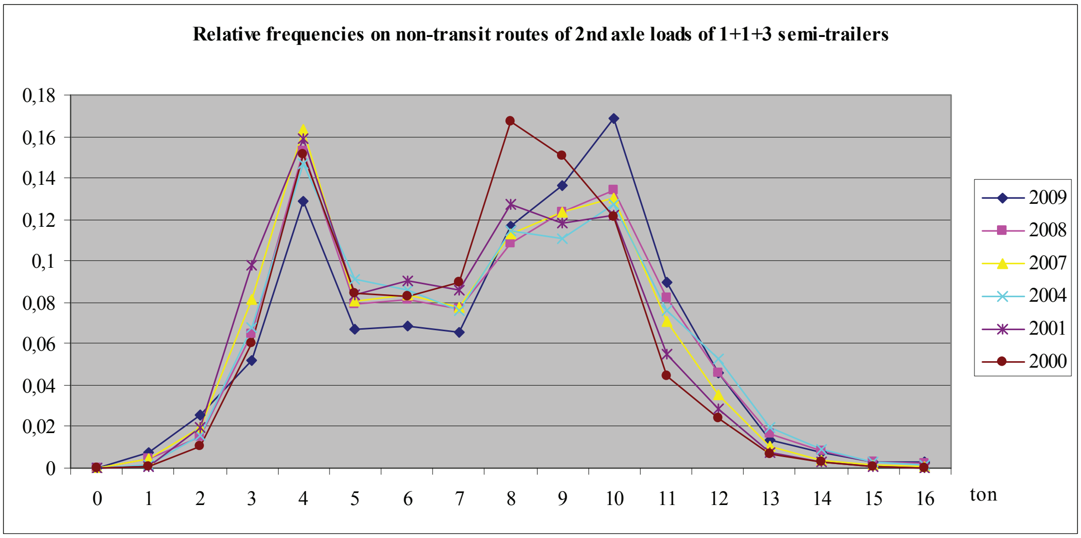

Fig. 4. Relative load frequency distribution on non-transit routes of 2nd axle loads of 1+1+3 semi-trailers

Table 4. Measured axle load data for analysis of axle load changes

	2000	2001	2002-2004	2007	2008	2009
thousand axles	299	684	1405	1867	3611	2757

An analysis of characteristics and differences in relative load frequency distribution functions has been performed considering the skewness of function curves (Equation 2).

$$S = \frac{n}{(n-1)(n-2)} \sum \left(\frac{x_i - \bar{x}}{s} \right)^3 \qquad (2)$$

where s is the standard distribution of the sample

Positive skewness means asymmetry on the right side of the function compared to normal distribution.

Table 5 and Figure 5 show skewness trend of relative load frequency distribution functions of 2nd axle loads of 1+1+3 semi-trailers on both transit and non-transit routes between 2000 and 2009.

In the case of axle loads the more positive is the skewness the more axles are loaded at or over the legal load limit. The skewness is higher on transit routes in all but one case that means semi-trailers on transit routes have higher axle loads than those on non-transit routes. Moreover the skewness on transit routes is clearly increasing in time consequently there are higher axle loads in recent years (2007-2009) than a few years earlier (2000-2004).

Table 5. Skewness trend of relative load frequency distribution functions of 2nd axle loads of 1+1+3 semi-trailers

	2000	2001	2004	2007	2008	2009
non-transit	0,615	0,308	0,213	0,409	0,364	0,659
transit	0,414	0,501	0,316	0,579	0,767	0,884

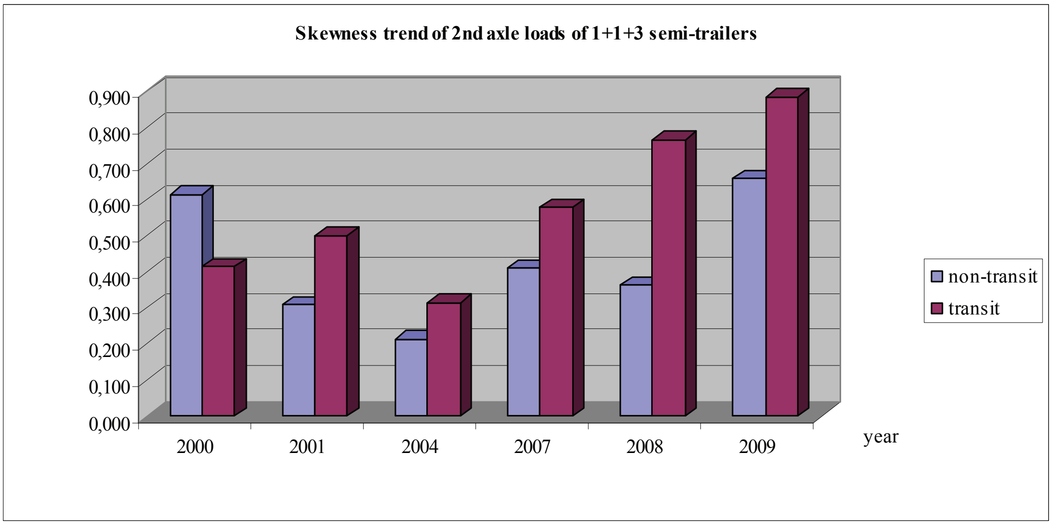

Fig. 5. Skewness trend of relative load frequency distribution functions of 2nd axle loads of 1+1+3 semi-trailers

6. Effects of axle load trends on pavement design guide

The Hungarian flexible pavement structural design guide is based on the use of 10 ton equivalent standard axle loads (ESAL), calculated from dynamic weight measurements providing a more realistic basis for pavement structural design (Ishak, Shin and Sridhar). The ESAL factors have been regularly re-calculated in every 2-3 years and when changes proved to be statistically significant, the ESAL table in the design guide was modified (Gulyas).

According to the trends of heavy traffic growth a new design load class has been introduced in 2005 in the revised issue of the structural design guide for flexible pavements called “especially heavy” over 30 million ESALs during the designed lifetime of the pavement. This design guide covers pavement strengthening design principles and practice as well.

7. Pavement strengthening program in Hungary

A pavement strengthening program has been started on the TEN-T and E-roads in order to comply with the EU 11,5 ton axle weight limit regulation. Realistic axle load spectra and axle load trends based on WIM measurements have been taken into account in the structural design of strengthened pavements.

Hungary has got a derogation concerning maximum permitted axle load until 2008 undertaking to implement a pavement strengthening program of 2265 km on main roads. Due to different obstacles and financial circumstances up to 2010 an amount of 1352 km has been constructed (Table 6). This amount is about 20% of the total Hungarian main road network (6614 km without motorways and high-speed roads). Strengthening works have been concentrated on sections of TEN-T and E-road networks. Financial background consisted of an increasing EU fund incorporation resulting that two third of overall strengthened length was implemented by EU co-financing.

Table 6. Results of pavement strengthening program in Hungary [km]

	2002	2003	2004	2005	2006	2007	2008	2009	2010	total
domestic	36,2	106,8	78,9	107,6	107,5	10,5	18,2	2,7	0,7	469,1
EU co-financing	7,3	24,4	21,1	41,5	331,5	136,4	96,4	93,2	131,4	883,2
sum	43,5	131,2	100,0	149,1	439,0	146,9	114,6	95,9	132,1	1352,3

8. Conclusion

A network of about 30 weight-in-motion (WIM) sites has been implemented in Hungary in 1996. Since then measurements have been performed regularly until 2010. Measured data series provide a possibility for analysing axle load trends in the past 10 years. Both axle loads and total weights of heavy vehicles show an increasing tendency in accordance with the growth factors of heavy traffic. The proportion of semi-trailers has increased significantly. Overloaded axles occurred mainly at the 2nd axle of semi-trailers with 5 axles (pattern 1+1+3).

Axle loads are the highest on the second (driven) axle of the 1+1+3 semi-trailer therefore a detailed time-series analysis has been made distinguishing between cases of transit and non-transit routes. In both cases (transit and non-transit routes) axle loads showed a definite increase in time. However this increase is more characteristic in case of transit routes where clear clusters can be identified for 2000-2004 and for 2007-2009. Comparing axle loads on transit and non-transit routes some other important findings are as follows. Proportion of empty runs (the first peak on the curve) is higher on non-transit routes, in domestic transport. Proportion of overloaded axles is higher as well on non-transit routes since in transit transportation there are weight control stations at border crossing points, this fact implies a demand for better enforcement in case of domestic heavy vehicles. On transit routes more vehicles are loaded up to legal limits (concerning axle loads and gross weight as well) than on non-transit routes.

The Hungarian flexible pavement structural design guide is based on the use of 10 ton equivalent standard axle loads (ESAL), calculated from dynamic weight measurements provided a more realistic basis for pavement structural design. The ESAL factors have been regularly re-calculated in every 2-3 years and when changes proved to be significant, the design guide has been modified. According to the trends of heavy traffic growth new design load classes were incorporated into the design guide a few years ago. A pavement strengthening program has been started on the TEN-T and E-roads in order to comply with the EU 11,5 ton axle weight limit regulation. Realistic axle load spectra and axle load trends have been taken into account for the structural design of strengthened pavements.

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